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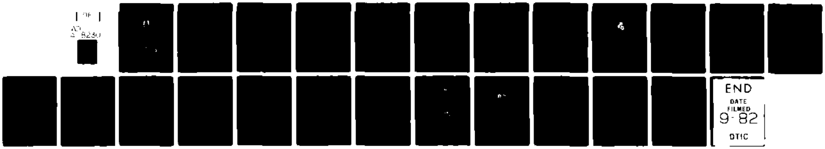

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FOREIGN TECHNOLOGY DIVISION

SPACEFLIGHT

(Selected Articles)

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PREPARED BY:

TRANSLATION DIVISION
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SPACECRAFT STRUCTURAL SYSTEMS

Wu Jiansheng

Spacecraft structural systems hold an important place in the totality of a spacecraft. A man-made satellite for example, no matter how complex a satellite may be, can only be perceived once it has a structure, and that is what determines its shape, appearance and size. For this reason, it often happens that when someone is describing a satellite, they refer to the external structural form. This is just like describing what sort of person someone is by describing their appearance. Clearly the most important effects of the structural systems are more than this. To better understand the structural systems of spacecraft, let us start by considering their operating conditions.

Complex Operating Conditions

We know that spacecraft must travel from the surface of the Earth into space. The Earth is surrounded by a thick layer of atmosphere. As far as human beings and other living creatures are concerned, the atmosphere is essential. However, as far as spacecraft are concerned, the very existence of the atmosphere is a factor hindering spacecraft. What then are the conditions to which a spacecraft going into space will be subjected? Firstly, as far as the forces it will experience are concerned, there is the effect of the thrust generated by the engines of the launch vehicle. We will indicate this by P.

Because of the existence of the atmosphere, a spacecraft undergoes the effect of atmospheric drag. This is called total drag. This drag may be subdivided into frontal drag - X, and lift - Y.

The Earth's core exerts an attaction upon a spacecraft. This will be indicated as the force of gravity - Mg. The rockets must overcome drag and the force of gravity before a spacecraft can lift off.

Besides this, every rocket engine has control mechanisms (such as jet vanes), and these generate corresponding jet vane drag - Xg, and jet vane lift - Yg. The acceleration of a rocket also produces opposing inertial forces - Mv, and normal inertia - Mvθ. In addition to the above-mentioned forces, there are also moment forces, such as the resultant moment - M; inertia moment - Iϕ and the jet vane hinge moment - M_L. If these forces were to be depicted in a diagram, they would appear as shown in Figure 1.

As a result of these forces and moments, the structure of a spacecraft is subjected to longitudinal load, lateral load, as well as the effects of bending, twisting and shearing.

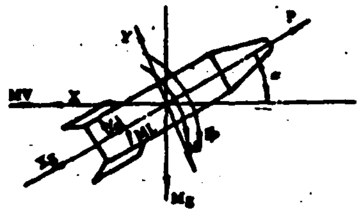

Fig. 1. Forces acting upon spacecraft structure.

Secondly, at the moment of ignition and shutdown of the rocket engines, violent shocks are produced; engine operation and atmospheric friction can set up dissimilar frequency vibration and aerodynamic noise (which is transmitted through the structure). Besides producing drag, atmospheric friction can also cause the phenomenon of aerodynamic heating, which causes the temperature of the outer shell of the structure and of the inner components to rise.

Thirdly, once a spacecraft has gone into its predetermined orbit, it is then subjected to the effects of high vacuum and all kinds of cosmic radiation. Without effective protective measures, the on-board instrumentation might suffer damage and certain components of the structure itself may be changed. In space, a spacecraft must operate in temperature extremes from +100°C to -100°C. The temperature conditions of a spacecraft are affected by not only solar radiation but also by the heat radiated from the Earth and the heat generated by electronic instrumentation in operation. Figure 2 shows some of the types of temperature effects. Recoverable satellites and spacecraft designed to reenter the atmosphere are subjected to even more adverse conditions than those described above.

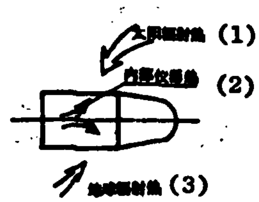

Fig. 2. Some types of temperature effects.

Key: (1) Solar radiation, heat; (2) Onboard instrumentation heat; (3) Radiated heat from the Earth.

Functions and characteristics of structural systems

The successful accomplishment of a mission by a spacecraft depends upon the on-board instrumentation, yet the preservation of normal operation of the instrumentation installed depends upon the structure. The following summarizes the functions of the structural systems of a spacecraft:

1. It is the skeleton of a spacecraft, making up its main body, and giving it its shape.

2. It accomodates and holds secure all the on-board instrumentation.

3. It withstands the effects of all kinds of conditions. Therefore the structure must have sufficient strength and rigidity to effectively withstand all kinds of loads and the effects of various conditions without failing or exceeding permissible limits of deformation.

4. It must provide protection for the instruments from the effects of adverse conditions, such as heat protection and radiation protection, and provide a sealed compartment for instruments that cannot operate in conditions of high vacuum. In this compartment, a fixed pressure, temperature and humidity must be maintained.

The most important characteristics of and demands upon a spacecraft structure are as follows:

It must be strong enough to have sufficient strength and rigidity to operate with acceptable performance in high and low temperatures, with stability under radiation conditions, and under conditions of violent loading.

It must be light, for lightness is of prime importance in spacecraft and is the most important factor in design. At the moment of launch,

the carrying capacity of the launch vehicle and the weight of the payload (such as a satellite) have a proportionate relationship of 1 : 100, that is to say, for every one kilogram that the weight of the payload is increased, there must be an increase in the carrying capacity of the launch vehicle of 100 kilograms. And that is the way things are with launch vehicles. If the lift-off weight remains unchanged, for every reduction in the weight of the structure, the speed of the rocket can be increased. Therefore weight reduction is not merely advantageous from the economic point of view, but it is also connected with whether or not a launch vehicle can carry a heavier effective payload. As far as satellites are concerned, to reduce the weight of the structure means that the same launch vehicle can carry more instrumentation thus allowing more tasks to be undertaken; or if the circumstances of the mission remain unchanged, then a reduced launch vehicle carrying capacity will be required.

It must have high reliability, for not all the components in a spacecraft are fixed, as some of them are moving parts which must come into operation at specific times during the course of a flight. For example, the automatic opening and closing compartment hatches must open; the antennas must extend; the solar sails must be deployed; the launch vehicle and the satellite must separate, and all these are automatic operations. Some of these operations must take place with precision down to the exact millisecond, and must therefore have very high reliability to ensure that all the components operate in coordination.

The structure of the sealed compartment demands even tighter tolerances, as leakage of even a dozen millimeters of mercury pressure over a period of a few days is not permitted. Even the most minute structural change in the sealed compartment may result in damage bringing about a failure.

Structural Shape and Materials

Spacecraft structures vary greatly in shape and appearance. In summary there are several main types of structural main component (the main compartment):

Firstly, there is the structure which consists of stringers, ribs and skin. Many satellites, aircraft and rockets use this semi-monocoque structure. This structure which was developed some time ago, and is in widespread use, consists primarily of stringers, ribs and skin. The stringers are the longitudinal load-bearing component, the ribs are the lateral load-bearing component and the skin on the outside of the

stringers and ribs is a thin wall which also takes part in the load bearing. This structure usually uses welded or rivetted joints to ensure an aerodynamic form. The two ends of the stringers are joined to the bulkhead of the main compartment. This simple and stable structure is often used for the load-bearing shell of evacuated sealed compartments.

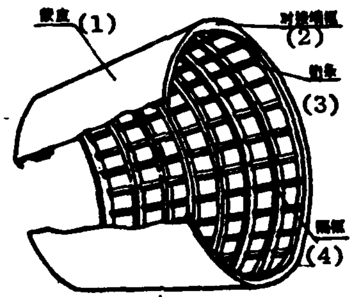

Fig. 3. Stringer, ribs and skin structure.
Key: (1) Skin; (2) Bulkhead; (3) Stringers; (4) Ribs.

Another type is the skin structure which consists entirely of a sealed shell formed by the skin, which is connected to the bulkheads at each end. A number of stringers (for longitudinal load bearing and for reinforcement) are attached to the inner surface of the skin. (See Figure 4). The most important use for this structure is in the sealed compartment, which, besides requiring excellent strength and rigidity, also needs perfect air-tightness.

A third type of structure is the chemical milled network structure. The construction of this type of structure consists entirely of thick plate upon which an anticorrosive layer is applied and then a chemical solvent is used to remove the surplus metal, leaving the component form required. The surface then takes the form of different shapes and this gives the reinforcement in the form of a network. This type of structure is most suited for spacecraft because it has the advantage of not requiring rivets and only a small amount of welding, which reduces the weight and minimizes the risk of weld failure, while the inner surface is completely smooth and shiny, and, with its fully woven inner layer, is strong and highly rigid, and has excellent airtightness.

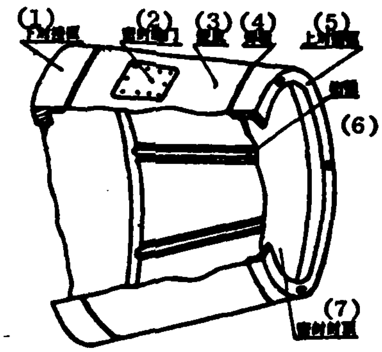

Fig. 4. Skin structure.
Key: (1) Lower bulkhead;
(2) Sealed compartment hatch;
(3) Skin; (4) Weld; (5) Upper
bulkhead; (6) Stringer;
(7) Airtight seal.

As space technology has continuously developed, honeycomb sandwich structure has appeared. In this type of structure, a hollow honeycomb layer is sandwiched between two thin plates. The typical honeycomb layer is made up of aluminum (foil) or glass fiber reinforced plastics.

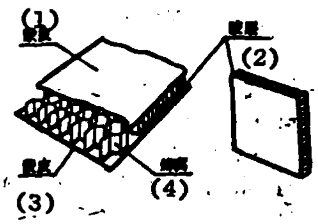

Fig. 5. Honeycomb sandwich structure.
Key: (1) Skin; (2) Adhesive layer; (3) Skin; (4) Honeycomb.

This is generally made up of six-sided cells or some other from bonded together with a layer of adhesive as is shown in Fig. 5. As this type structure has excellent strength and lightness, as well as outstanding rigidity, it is being used very widely in aircraft and spacecraft.

The above-mentioned types of structures are the forms most often used for the main components of spacecraft. There are the other components such as compartment hatch covers, supports, and observation windows etc which all have their own structures, so we will not list them one by one. Because of the specific demands brought about by the particular conditions experienced when reentering the atmosphere, spacecraft designed to reenter have their own particular structure.

The choice of materials for particular spacecraft structures likewise entails equally important questions. Materials for spacecraft structures and their properties have been continuously improving. The most widely used are the non-ferrous lightweight metal products, of which the most popular have been aluminum alloys, as they have high specific strength and rigidity, as well as being easy to work and have anti-corrosion stability. Besides this, the specific gravity of aluminum alloys is only one third that of steel. It may be used for the load-bearing components of spacecraft such as the skin, stringers, ribs, bulkheads, etc. In recent years, aluminum/magnesium alloys have been widely used.

Another widely used material has been titanium alloy. Titanium alloy has a whole range of advantages: strength, comparatively low specific gravity (4.4 approximately), high temperature strength, excellent thermal stability and corrosion resistance. It has generally been used for the medium strength key components in spacecraft.

In addition, spacecraft designed to reenter the atmosphere have often used the non-ferrous metals which are difficult to work such as : nickel-base alloys, beryllium alloys, molybdenum alloys, and even niobium alloys etc. These materials have the advantage of high temperature stability, but the disadvantage that they are difficult to work, are very expensive and some are toxic.

Ferrous metals are used relatively seldom, being employed only in the isolated cases of rocket engine components, high pressure gas cylinders and tubing where stainless steel is the preferred material.

It should be mentioned that plastics are receiving ever increasing attention as materials for spacecraft structures, as they have the outstanding advantage of lightness with a specific gravity that is very low (generally between 1 and 2, some even as low as 1). In particular, the appearance of high quality high strength fiber reinforced plastics

has caused major development of structural plastics.

Heat-proof materials for recoverable type spacecraft employ non-metallic oblative heat-proofing materials which are the most effective from the viewpoint of present conditions of use.

From the simple introduction above it can be seen that structural systems in spacecraft occupy an extremely important position. The quality of structural design, and whether or not materials are properly selected are directly related to the quality of the spacecraft. With the continuous development of technology, spacecraft structures will become more perfect, rational and advanced.

LIQUID-FUEL ROCKET ENGINE 'FOOD' - DEVELOPMENT AND PROSPECTS FOR LIQUID PROPELLENTS

Written by Liu Songwen. Illustrated by Nie Jingtao.

One of the materials consumed by rocket engines is called the combustible component (the fuel), and the other is called the oxidant. Together they are called the propellent. If both the oxidant and the combustible component are liquids, it is then called a liquid propellent; if they are both solid, then it as called a solid propellent; if one is solid and the other liquid, then it is called a solid/liquid mixture propellent. Of course the 'food' for a liquid-fuel rocket engine is a liquid propellent. Apart from determining aspects of the design of a liquid-fuel rocket engine, the characteristics of a particular liquid propellent are a very significant factor affecting the performance of a liquid-fuel rocket engine.

There are three types of propellents: three component propellents; two component propellents; single-component propellents. If a third component is added to a two component propellent, it then becomes a three component propellent. The third component selected is usually hydrogen which has a very low molecular weight. This maximises the advantage that two component propellents have of a high combustion temperature, remedies the low average molecular weight of the combustion products which lowers the specific impulse, and produces a high specific impulse three component propellent. Tried propellents that give a specific impulse of 400 seconds or better are boron hydride/fluorine/hydrogen, boron hydride/oxygen/hydrogen, lithium/fluorine/hydrogen, aluminum hydride/fluorine/hydrogen, boron hydride/hydrogen peroxide/hydrogen, etc.

One single component propellent is called Otto fuel. This is in fact a type of propyl nitrate and was invented by Dr Otto in the U.S.A. and that is how it got its name. Its most important application is in

torpedoes. There are hopes of using it in upper stage rockets and in the attitude control jets of the space shuttle, to solve the problems associated with repeated start up and shut down.

There is also a single component propellent which consists of 70% ammonium difluoride and 30% tetranitromethane, which has a density/specific impulse of as much as 461 seconds. There is also a company in Seattle in the U.S.A. which is said to have developed a single component propellent called MONEX which they say can be used in engines with thrust varying from 5 to 100 tons.

The following discussion will concentrate on two component propellents.

Development and Prospects

Generally speaking, since the days of the German V_2, the development of propellents has been divided between low energy (short range), medium energy (medium range) and high energy (long range) propellents.

Although after the Second World War, each country used the V_2 as the starting point for developing their own engines, the path followed by each country since that time has been different. For instance, the U.S.A. went from liquid oxygen/ethyl alcohol to liquid oxygen/kerosine to nitrogen tetroxide/hydrazine based fuels to liquid oxygen/liquid hydrogen in their development of propellents for liquid-fuel rockets; while the U.S.S.R. went from liquid oxygen/ethyl alcohol to liquid oxygen/kerosine to nitric acid (nitrogen tetroxide)/unsymmetrical dimethylhydrazine.

As can be seen, the U.S.A. has no unsymmmtrical dimethylhydrazine stored on its own, but they do have 50/50 hydrazine based fuels (50% hydrazine with 50% unsymmetrical dimethylhydrazine). Now they are using liquid oxygen/liquid hydrogen as a high energy propellent for upper stage engines on a large scale. There are no indications that the U.S.S.R. is intending to use liquid oxygen/liquid hydrogen in the near future.

Medium energy storable propellents such as nitric acid in an oxidant, nitrogen tetroxide; a 50% hydrazine base in a fuel, unsymmetrical dimethylhydrazine, nowadays have an important role in launch vehicles. In the last ten years or so, liquid oxygen/liquid hydrogen has been a particularly important high energy propellent, particularly as an upper stage propellent for civilian applications. Outside the U.S.A., Western Europe and Japan have been deleloping liquid oxygen/liquid hydrogen as a propellent for the Ariane, N-1 and N-2 launchers which are designed to put up their own satellites.

At present, there are two directions for the development of liquid propellents. One is to improve existing propellents, and the other is to discover new, higher performance propellents to satisfy the demands of the aerospace industry.

Improvements to Existing Propellents

Improving propellents means changing their particular physical and chemical properties. When the U.S.A. wanted to raise the payload of their launch vehicles, they decided to use high density nitric acid in the Agena rocket engine. They raised the content of nitrogen tetroxide from 13 - 15% to 44 - 46% which raised the density 0.1 - 0.15, and raised the specific impulse by 6 seconds. (Specific thrust is also called specific impulse which is the thrust produced by burning one kilogram of propellent in one second).

The most disadvantageous aspect of nitrogen tetroxide is that its ice point is too high (-12.2 degrees C.). There are reports that in the past, this problem was solved by adding nitric oxide, tetranitromethane, nitromethane, or difluorohexanitroethane, etc. More recently, some people have suggested that adding nitromethane can both lower the ice point and raise the density. To solve this problem, mixtures consisting of oxides of nitrogen can be used. One possible mixture is 88.8% nitrogen tetroxide with 10 - 12% nitric oxide. The ice point of this mixture is -22.9 degrees C. and the density is somewhat higher.

Unsymmetrical dimethylhydrazine is a storable launch vehicle propellent that has been used quite widely. If 0.9 - 1.0% silicon oil or polysiloxane is added, this raises the density 3%, the specific impulse 6 seconds and reduces the heat flow density of the combustion chamber walls 33%.

Hydrazine is seldom used in two component propellents because it has a high propensity to gas phase explosion, its ice point is high and its thermal stability is not good. 2.5% methylhydrazine can be added to lower the risk of gas phase explosion. To overcome the high ice point and put thermal stability within the high performance demands of the aerospace transportation industry which requires reusability and long life, methylhydrazine is added in the proportion 50% hydrazine and 50% methylhydrazine. If this mixture is used with nitrogen tetroxide, it can be a storable propellent for use in space.

Monomethylhydrazine is used as a single component propellent. The U.S.A. however has recently mixed monomethylhydrazine and nitrogen tetroxide to produce a two component propellent for use in two small-scale improved attitude control jets. The U.S.A has also switched over to using a 50/50 mixture of monomethylhydrazine and unsymmetrical dimethylhydrazine in the large boosters of the Atlas II rocket. The Soviet Union

is also planning to use the above mixture in the boosters of their three-stage launch vehicle, the Lenin, which is even larger than the American Saturn rocket.

Along with the development of the cruise missile and the demand for propellents with even higher specific impulse, improvements have been made to a hydrocarbon fuel resembling kerosine. The normal density of hydrocarbon fuels is 0.85, while the density of two improved hydrocarbon fuels (called RJ-5 and J$_p$-9) is 1.08 and 0.995 respectively. The U.S.A. has already made the decision to replace the hydrocarbon fuel used previously - J$_p$ 4 - with J$_p$ 9, in the subsonic cruise missile. The U.S.A. is still attempting to use a kerosine fuel - R$_p$ 5- together with liquid oxygen to replace liquid oxygen/kerosine R$_p$ 1 in the Space Shuttle. There have been recent reports that the solid-fuel booster of the Space Shuttle is to be replaced by a liquid-fuel booster to reduce the atmospheric pollution caused by the combustion products of the solid propellent. Besides liquid hydrogen, these improved hydrocarbon fuels may be usable in this liquid-fuel booster.

New Propellent Research

To satisfy the requirements of the aerospace and defense industries, all countries are conducting extensive research into new propellents. Ever increasing numbers of new propellents are appearing on the scene. We will mention just a few.

Chlorine pentafluoride. This is an extremely powerful oxidant, which, if combined with anhydrous hydrazine or 50/50 hydrazine based fuels can produce a relatively high performance liquid propellent with a specific impulse of 300 seconds or more. Chlorine pentafluoride is the oxidant with the best prospects of being used in intercontinental ballistic missiles and spacecraft.

A number of halogen compounds are also being researched. These include chloroxytrifluoride, iodoxypentafluoride, perchlorylfluoride, trifluoroamine, etc.

Liquid fluorine. Low temperature liquid chlorine which has a high specific gravity and high specific impulse, has been receiving considerable attention in recent years. For example, NASA has recently been developing a high performance engine using the two component propellent difluoro-hydrazine for use in interplanetary flights in the late 80's. To this end they have been experimenting with an all carbon material engine using difluorohydrazine to develop 363 kilograms of thrust, with a specific impulse of 376 seconds. Specific thrust of this order is not often

encountered unless liquid oxygen/liquid hydrogen is being used. West Germany has conducted a heat run on a carbon engine using a combination of fluorine and hydrogen - difluoroamine - and using hydrogen as a regenerative coolant. The level of specific thrust achieved is thought to have matched or exceeded that of liquid oxygen/liquid hydrogen.

A mixture of fluorine and oxygen (FLOX). This is a mixture of 70% liquid fluorine and 30% liquid oxygen. The U.S.A. has added 70% liquid fluorine to the oxidant - liquid oxygen - in the Saturn rocket, and experiments have shown a greatly enhanced specific impulse.

Liquid hydrogen. Added to liquid oxygen, this can produce a very high performance propellent that has been used more and more widely in recent years. The successful maiden flight of the Space Shuttle demonstrated the unlimited longevity of liquid hydrogen. Whether it is used or not has now become the test of how advanced a particular aerospace industry has become.

At the same time, the development of cryogenic technology in the last ten years or so has permitted liquid hydrogen to be used in aircraft, land vehicles and for civilian uses. It is available in unlimited quantities (the oceans contain 1.7×10^{17} tons of hydrogen), and when used with liquid oxygen, it produces a high performance non-polluting propellent that does not harm the ecology. For these reasons, liquid hydrogen is receiving much attention in many quarters.

The End.

SPACE TUGS

Written by Lin Yiping. Illustrated by Fu Wancheng.

Standing by the Yangtse River, long strings of boats may be seen meandering along the river, looking like a railway train. The powered boat at the head of the string is known as the tug. Besides being used to pull barges, tugs are also used to pull log rafts, ships in distress, floating docks and floating cranes, as well as for towing large vessels in and out of harbors and shipyards.

As space technology has developed, the need has arisen for tugs in space. These are called space tugs. They belong to the general category of spacecraft. The job of a space tug is to go backwards and forwards from low orbits to high orbits, from planet to planet, delivering and recovering all kinds of space vehicles (as well as sections, components and parts): space laboratories, applications satellites (communications satellites, probes, weather satellites, navigation satellites, etc), assembling large space telescopes for use on space observatories, assembling the sections, components and other space materials for satellite solar power stations.

Space Tug Structure

Space tugs look nothing like the space shuttle, having no wings or tail section. In fact they look more like one stage of a launch vehicle. This is because space tugs operate outside the atmosphere, never directly leaving orbit to return to Earth, unaffected by aerodynamic influences in a very high operating orbit, and thus require no aerodynamic components.

The main component parts of a space tug are: fuselage, docking devices, power plant, electronic systems, auxiliary systems, etc.

The fuselage or main body of the space tug can be used to transport men or materials, and its structure resembles that of a regular launch vehicle. It must be sufficiently strong with a certain degree of rigidity, being capable of withstanding the effects of various forces; it must be able to withstand vibration; the external walls must be able to resist the impact of meteorites etc. It must also have certain life support systems.

The forward section of a space tug is equipped with docking devices to allow docking with towed vehicles to be effected. As any Yangtse River tug-master you meet will tell you, there are two ways for a tug to move a barge; one way is 'pulling' and the other is 'pushing'. As space tugs and their 'barges' are connected together firmly at close range, the most widely preferred method is 'pushing', to prevent the 'barge' from becoming charred by the jet exhaust flow of the tug's engines. Both attitude control and maneuvering sensitivity are much easier using this method. Docking between a space tug and a 'barge' is accomplished by varying the relative motion of the two bodies. Once the two bodies are locked together, materials must be delivered or supplied, power storage systems must be recharged, and men transferred (or rescued). For this reason, the docking devices must allow unimpeded flow of water, electricity and gases, as well as being of precisely compatible design.

The power plant of a space tug consists of the main engine and the auxiliary engine. The main engine of a space tug usually consists of a liquid fuel rocket, while the auxiliary engine is most often a solid fuel rocket. The specific thrust of liquid fuel rocket engines is relatively great with a long duty cycle and the amount of thrust can be controlled. Liquid fuel rocket engines can be ignited, shut down and ignited again repeatedly. Solid fuel rocket engines are smaller with a less complex structure. They are reliable and may be stored for long period of time and then brought into operation at a moments notice. Only a few grams of thrust are required by a solid fuel rocket engine to adjust the orbit of a spacecraft. In the design of a space tug, account must be taken of the fact that the duties of a space tug will differ and the flying time of particular missions will vary. Thrust will be required in two different modes, and the correct mode must be selected. Large amounts of thrust may be required in a short duty cycle or small amounts of thrust may be required over a long duty cycle. Many different types of power plant for space tugs are being developed in various countries, and a number of different power supply systems are also being selected.

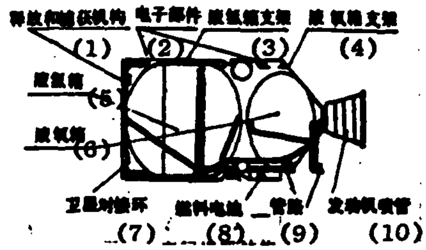

Fig. 1. Space tug structure.
Key: (1) Docking and release mechanism; (2) Electronic components; (3) Liquid hydrogen tank support; (4) Liquid oxygen tank support; (5) Liquid hydrogen tank; (6) Liquid oxygen tank; (7) Satellite docking ring; (8) Fuel cells; (9) Ducting; (10) Rocket nozzle.

Considered from the standpoint of what is possible in the short term, the preferred option is to modify an existing launch vehicle (such as the Atlas III C, the Centaur, the Titan, the Agena, etc). See Figure 2.

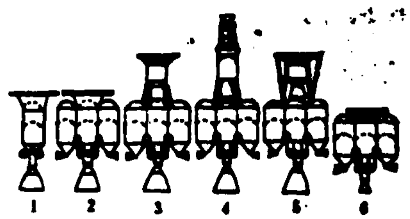

Fig. 2

This will mean that the technology is more familiar, which will reduce the development time and save development cost. Besides these factors, different power plant configurations will need to be selected according to the various types of vehicles that a space tug will be called upon to move. If the vehicle to be moved is small and light or large and light, a single stage tug can be selected; if the vehicle to be moved is large and heavy, a multiple stage tug or several tugs linked together in series will be needed. (See Figure 3).

The electronic systems on board a space tug include guidance, navigation, control, communications, tracking, display, computer, instrumentation, software and data processing, electrical control systems, etc, and these must all be reliable, integrated, with visual monitoring, low power consumption, interference protection, and must operate for long periods of time under complex conditions. Every single

component throughout the entire system must be lightweight, as small weight savings on individual components adds up to possible significant weight savings overall.

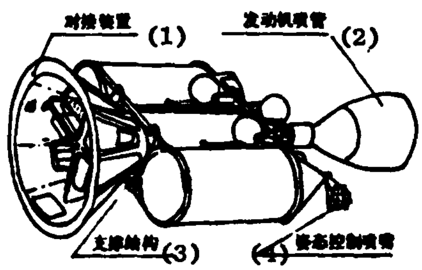

Fig. 3.
Key: (1) Docking device;
(2) Rocket nozzle; (3) Support
structure; (4) Attitude control
jets.

(Translator's Note: Fig. 2 and Fig. 3 are numbered as in original. It appears that these should be transposed.)

Every auxiliary system on board a space tug likewise has an important function. For example, the temperature control systems must automatically regulate the temperature variation to ensure that every component on a space tug operates at its correct temperature. The fuel cells must make it possible for the space tug to operate over extended periods of time.

Tug Navigation.

Space navigation is a prime consideration when towing in space. The process of space towing is analogous to the relay race in track and field sports. To accomplish long distance navigation, the vehicle being towed must be moved from one station to the next until the destination is reached. Why not do it like a marathon race and deliver it to the required point in one trip? As we know, not everyone's strength is up to the demands of the marathon. In the same way, not every launch vehicle is adequate to deliver a space load to a distant location in space. If one single launch vehicle were to be used for the launch and to transport the load to a distant point in space, it would need to carry large quantities of propellent, which would greatly increase the lift-off weight, requiring more rocket engine thrust, and this would lengthen launch preparation time, increase the amount of technical checks, and

end up quite uneconomical and disadvantageous. So, under the circumstances, the relay race method is adopted for space towing.

The first leg of the relay towing operation is the task of the launch vehicle which must place a space shuttle in orbit and then return through the atmosphere to the ground. The second leg of the relay operation is taken by the space shuttle which carries the space tug and the vehicle to be towed stowed in the cargo bay up to a circular orbit 270 kilometers high. They are then removed from the cargo bay by a mechanical arm and separation takes place. The space tug then starts its engines and flies to a geosynchronous orbit, a planetary orbit, or some other orbit. When it reaches its destination, the load being carried is delivered or a new load picked up and the return flight begins. One single towing mission may require many relay processes to be undertaken.

To establish a load on an interplanetary trajectory normally will require two separate sequences of boost. The first boost sequence will establish the load in an elliptical orbit. Then, when the space tug reaches the apogee of the elliptical orbit (this is the moment when the Earth's gravitational attraction is least), the second boost sequence is carried out, accelerating the object being towed to escape velocity. The tug then releases the load, fires its retrorockets and reenters an elliptical orbit.

The End.

REFERENCE

Existing Non-Chinese Launch Vehicles

Compiled by Xiang Yang

Name (Country)	Engines			Length (m.)	Diameter (m.)	Launch Weight (kg.)	Payload (kg.)	Remarks
	Stage	Number of Units (and Type)	Thrust (kg.)					
Scout SLV-1A (U.S.A.)	1 2 3 4	1xAlgol3A (Solid) 1xCastol2A (Solid) TX354-3 1xAntares2B (Solid) X259-B4 1xAltairs3 (Solid)	48900 28000 12700 25800	22.9	1.13	21400	250	4-stage small-scale solid-fuel launch vehicle. Low-cost, reliable, success ratio >95%
Kosmos C-1 (U.S.S.R.)	1 2	2xRD216 (Liquid) 1xRD114 (Liquid)	176000 25000	19.3 7.0	2.44 2.44	80000	1000 (est.)	2-stage medium-scale liquid-fuel launch vehicle. Most widely used.
M3H/M-3S (Japan)	1 2 3 3	1xSolid-fuel engine 8xSolid-fuel boosters (cluster) 1xSolid-fuel engine 1xSolid-fuel engine	97200 77600 28300 5800	19.4 4.0 4.6 2.0	1.41 0.30 1.41 1.14		270	3-stage solid-fuel launch vehicle. 1st stage equipped with 2 liquid-fuel variable thrust devices.
Saturn F (U.S.A.)	1 1/2	1xLR-105-NA, (Liquid) 2xLR-89-NA, (Liquid)	25800 150000		 3.05	120000	600	Medium capability, multi-purpose launch vehicle.
Saturn/Agena D (U.S.A.)	1 1/2 2	1xLR-105-NA (Liquid) 2xLR-89-NA, (Liquid) 1xRL-81-13A, (Liquid)	25800 150000 7250	 7.1	3.05 1.5	120000 6810	3700	Most widely used launch configuration of Saturn series.

(Continued from previous page)

Name (Country)	Engines			Length	Diameter	Launch Weight	Payload	Remarks
	Stage	Number of Units (and Type)	Thrust (kg.)	(m.)	(m.)	(kg.)	(kg.)	
Saturn/	1	1xLR-105-NA$_5$ (Liquid)	25800		3.05	120000	1800	A standard U.S. launch
Centaur	1/2	2xLR-89-NA$_5$ (Liquid)	150000					vehicle at present.
(U.S.A.)	2	2xLR-10A-3^5-3 (Liquid)	13600	9.1	3.05	15900		
	1	1xMB-3 (Liquid)	78000	21.5	2.44	90300	1200	Successful utilization of
N-1		3xTX354-5 (Solid)	70800	7.20	0.76		130	Titan technology imported
		(Cluster)						from the U.S.A.
(Japan)	2	1xLE-3 (Liquid)		5.40	1.60			
	3	1xTE-364-3 (Solid)		1.73	1.65			
	1	1xMB-3 (Liquid)				133000	350	Length-35.4m. Weight-135
N-2		9xTX354-5 (Solid)						ton. Same as N-1 + 6 addit
		(Cluster)						solid-fuel boosters on 1st
(Japan)	2	1xAJ10-118F (Liquid)						stage for total of 9.
	3	1xTE364-4 (Solid)						
	1	1xRS-27 (Liquid)	93000	22.4	2.44	133000	700	The U.S.A.'s most widely
Titan		9xTX354-5 (Solid)	212000	7.2	0.76			used, high-performance,
2914		(Cluster)						accurate, reliable 3-stage
(U.S.A.)	2	1xTR-201 (Liquid)	4466	5.89	2.44			medium-scale launch vehicle.
	3	1xTE364-4 (Solid)	6800	2.3	0.98			

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